

Figure 1. Schematic representation of the experimental design. The subjects were divided into two groups: the control group (CG) and the experimental group (EG). The CG was divided into two subgroups: the control group (CG) and the control group (CG). The EG was divided into two subgroups: the experimental group (EG) and the experimental group (EG). The CG was divided into two subgroups: the control group (CG) and the control group (CG). The EG was divided into two subgroups: the experimental group (EG) and the experimental group (EG).

(1) Field of the Invention

(2) Description of the Related Art

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Problems with spurious radiation from power supply lines going to active devices in such recent electronic integrated devices and wiring boards have been pointed out, against which such measures as the insertion of decoupling condensers or other concentrated constant components into the power lines have been implemented.

However, because the noise generated in higher speed implementations of electronic integrated devices and wiring boards contains harmonic components, signal paths exhibit a distributed constant behavior, and situations have arisen where measures against noise that presume conventional concentrated constant circuits are ineffective.

It is an object of the present invention to provide sheet-form high-frequency current suppression bodies that comprise magnetic material effective in countering spurious radiation from semiconductor devices and electronic circuits that operate at high speeds, as described above.

It is a special object of the present invention, moreover, is to provide a high-frequency current suppression body that comprises magnetic loss material exhibiting a large magnetic loss factor μ'' wherewith effective measures against

spurious radiation can be implemented with a magnetic body of smaller volume.

According to one aspect of the present invention, there is provided a high-frequency current suppression body that has a sheet shape comprising an adhesive layer or a pressure-sensitive adhesive layer on at least one surface of a magnetic thin film.

According to another aspect of the present invention, there is provided a high-frequency current suppression method, with which the high-frequency current suppression body described below is deployed either in tight contact with or in close proximity to an electronic circuit. In the high-frequency current suppression body, the magnetic thin film substantially composed of a magnetic loss material having an M-X-Y composition, where M is at least one of Fe, Co, and Ni, Y is at least one of F, N, and O, and X is at least one element other than M or Y, the aforementioned magnetic loss material being a broadband magnetic loss material such that the maximum value μ''_{\max} of the loss factor μ'' which is the imaginary part in the complex permeability of the magnetic loss material noted above exists within a frequency range of 100 MHz to 10 GHz and that a relative bandwidth bwr is not smaller than 150% where the relative bandwidth bwr is obtained by extracting a frequency bandwidth between two frequencies at which the value of μ'' is 50% of the maximum μ''_{\max} and normalizing the frequency bandwidth at the center frequency thereof; the size of the saturation magnetization of the aforementioned magnetic loss material is in a range that is from 60% to 35% of the saturation magnetization of a metal magnetic body consisting solely of the M component; and the magnetic loss material has a DC electric resistivity value larger than $500 \mu\Omega \cdot \text{cm}$.

According to still another aspect of the present invention, there is provided a high-frequency current suppression body formation method is obtained with which a magnetic thin film formed on one surface of a peelable sheet-form substrate is placed on an object, and by applying a pressure from

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Fig. 12A is a graph of the transmission characteristic (S21) of sample 1 based on an embodiment of the present invention;

Fig. 9 is a graph of an example of the frequency dependence of the μ'' of a sample 1 based on an embodiment of the present invention;

Fig. 10 is a graph of an example of the frequency dependence of μ'' affecting a comparative sample 1;

Fig. 11 is a diagonal view of a measurement system for observing the suppression effects of a high-frequency current suppression body consisting of magnetic loss material based on the present invention;

Fig. 12A is a graph of the transmission characteristic (S21) of sample 1 based on an embodiment of the present invention;

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Fig. 12B is a graph of the transmission characteristic (S21) of a composite magnetic body sheet that is a comparative sample;

Fig. 13 is a diagram of an equivalent circuit for a magnetic body based on an embodiment of the present invention;

Fig. 14A is a graph of R values calculated from the transmission characteristic of sample 1, according to an embodiment of the present invention; and

Fig. 14B is a graph of R values calculated from the transmission characteristic of a composite magnetic body sheet that is a comparative sample.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The history of the present invention will be described prior to describing embodiments of the present invention.

The inventors have previously invented a composite magnetic body exhibiting large magnetic loss at high frequencies, and discovered a method whereby the generation of spurious radiation from the semiconductor devices and electronic circuits noted earlier, etc., is effectively suppressed by deploying the composite magnetic body in the vicinity of a spurious radiation source. It is known from recent research on the active mechanism of spurious radiation attenuation using such magnetic loss that such arises due to the impartation of equivalent resistance components to the electronic circuits constituting sources of spurious radiation. Here, the size of the equivalent resistance component is dependent on the size of the magnetic loss factor μ'' of the magnetic body. More specifically, the size of the resistance component is equivalently inserted in an electronic circuit and is roughly proportional to μ'' and the thickness of the magnetic body when the area of the magnetic body is constant. Accordingly, a larger μ'' becomes necessary in order to obtain a desired spurious radiation attenuation with a smaller or thinner magnetic body.

The inventors, in the course of their research on soft magnetic materials using sputtering or vapor deposition methods, took note of the outstanding permeability of granular magnetic bodies wherein very fine magnetic metal particles are diffused uniformly in a non-magnetic body such as a ceramic, and conducted research on the microstructures of magnetic metal particles and the non-magnetic bodies surrounding them. As a result, the inventors discovered that outstanding magnetic loss characteristics are obtained in high-frequency regions when the concentration of magnetic metal particles in a granular magnetic body is within a certain range. Much research has been done to date on granular magnetic bodies having M-X-Y compositions, where M is a magnetic metal element, Y is either O, N, or F, and X is an element other than M or Y, and it is known that these are low-loss and exhibit large saturation magnetization. In these M-X-Y granular magnetic bodies, the size of the saturation magnetization is dependent on the volume ratio accounted for by the M component. Therefore, the ratio of the M component must be made high to obtain large saturation magnetization. For that reason, the ratio of the M component in an M-X-Y granular magnetic body for an ordinary application, such as use as a magnet core in a high-frequency inductor device or transformer or the like, has been limited to a range wherewith a saturation magnetization of roughly 80% or greater can be realized for the saturation magnetization of the bulk metal magnetic body consisting exclusively of the M component.

The inventors studied the ratio of the M component in granular magnetic bodies having the M-X-Y composition, where M is a magnetic metal element, Y is either O, N, or F, and X is an element other than M or Y, across a wide range, and discovered, as a result, that, with every composition system, large magnetic loss is exhibited in high-frequency regions when the magnetic metal M is present within a specific concentration range.

The highest region where the M component exhibits a saturation magnetization of 80% or greater relative to the saturation magnetization of a bulk metal magnetic body consisting exclusively of the M component is the M-X-Y granular magnetic body region of low loss at high saturation magnetization that has been widely researched for some time. Materials in this region are used in high-frequency micromagnetic devices, such as the high-frequency inductors mentioned above, because the values of the real-part permeability (μ') and the saturation magnetization are both large, but the ratio accounted for by the X-Y component that affects electrical resistance is small, wherefore electric resistivity is also small. For that reason, when the film thickness becomes thin, the permeability at high frequencies deteriorates in conjunction with the development of eddy current loss in the high-frequency region, wherefore these materials are unsuitable for use in comparatively thick magnetic films such as are used to suppress noise. In the region for the M component ratio exhibiting a saturation magnetization of 80% or less but 60% or more of the saturation magnetization of a bulk metal magnetic body consisting of only the M component, the electric resistivity is comparatively large at roughly $100 \mu\Omega\text{-cm}$ or greater. Therefore, even if the thickness of the material is on the order of several μm , the loss due to eddy currents is small, and almost all of the magnetic loss will be due to natural resonance. For that reason, the frequency dispersion width for the magnetic loss factor μ'' will become narrow, wherefore such materials are suitable for anti-noise measures, i.e. high-frequency current

In regions where the M component ratio is even smaller than in the region of the present invention, on the other hand, super-normal magnetism will occur because the magnetic interaction between M components will hardly appear at all.

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The inventors studied configurations wherewith, when applying such magnetic materials, it is possible to deploy them more easily and simply at the desired site, and thus arrived at the present invention.

Referring to Fig. 1, a high-frequency current suppression body 15 has a granular magnetic thin film 19 consisting of $\text{Fe}_\alpha\text{Al}_\beta\text{O}_\gamma$ formed on one surface of a synthetic resin sheet or film substrate 17 by sputtering. On top of the granular magnetic thin film 19, a synthetic resin coating 2 is provided for peeling and reinforcing the granular magnetic thin film. On the other surface of substrate 17, meanwhile, a bonding adhesive or pressure-sensitive adhesive layer 23 consisting of rubber or a synthetic resin or the like and, thereon, a peel-away sheet or removal sheet 25 are respectively provided. Here, the synthetic resin sheet or film substrate 17 may consist of a synthetic resin, such as polyethylene terephthalate (PET), polyester ether (PEEK), or polyimide, etc., so long as it is not deformed during processing or vapor deposition. For the bonding adhesive used for bonding adhesive or pressure-sensitive adhesive layer 23, a solvent system dispersion system resin, such as an acrylic acid ester, polyvinyl ether, polyvinyl ether, polystyrene, or polyvinyl butyral resin can be used. For the tacky adhesive, those same resins to which a tackifier containing rosin or a derivative of terpene resin or other terpene derivative, and a cyclopentadiene, phenol, xylene, or coumarone-indene resin, or a silicone, polyurethane,

fluorine, or acrylic rubber may be used, with that wherein fire-retardant, insulative, flexible silicone rubber is used being particularly preferable, but any bonding adhesive or tacky adhesive whatever can be used which has sufficient adhesive strength not to peel away from the synthetic resin sheet or film substrate configuring the substrate 2.

For the peel-away sheet 25, either a surface-treated paper or resin or the like can be used so long as it can be easily peeled away from the adhesive surface. And for the synthetic resin coating 5, anything can be used so long as it forms a comparatively elastic synthetic resin layer when applied and dried. Alternatively, a thermoplastic resin sheet may be pressed on under heat.

Referring to Figs. 2 and 3, the peel-away sheet 25 is formed on one surface side of the high-frequency current suppression body 15 having a predetermined size. After the peel-away sheet 25 is peeled away, the high-frequency current suppression body 15 is adhesively applied at the desired site.

In the example diagrammed in Fig. 3, a high-frequency current suppression body 27 is applied so as to cover the entire surface of mounted components 31 such as ICs or LSIs that have been mounted on a substrate 29.

The high-frequency current suppression body 27 can also be applied to strip lines or jumper lines (not shown).

Thus, by applying the high-frequency current suppression body 15, it is possible to suppress spurious electromagnetic radiation that is a source of noise and to suppress high-frequency noise from the outside.

In the first embodiment noted above, what is used for the granular magnetic thin film 19 is represented by $\text{Fe}_\alpha\text{-Al}_\beta\text{-O}_\gamma$, but, in the present invention, it is sufficient to use a magnetic body the composition whereof is expressed by the general formula M-X-Y, and the present invention is not limited to or by the first embodiment described in the foregoing. Also, either one or both of the

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substrate 17 or surface protection layer 25 may be omitted if it is easy to handle.

Referring to Fig. 4, a high-frequency current suppression body 33 according to a second embodiment of the present invention has a granular magnetic thin film 19 consisting of $\text{Fe}_\alpha\text{-Al}_\beta\text{-O}_\gamma$ formed by sputtering on one surface of a synthetic resin sheet or film substrate 35. On top of the granular magnetic thin film 19, a synthetic resin layer 37 is formed by application and drying which has a similar composition. Adhesive layers 39 and 41 are deployed on each surface. On the adhesive layers 39 and 41, peel-away sheets 43 and 45 are severally deployed. Accordingly, the high-frequency current suppression body 33 is formed which has an adhesive layer on both sides thereof. For the synthetic resin layers 43 and 45 and the adhesive layers 39 and 41, the same materials as were used in the first embodiment can be used.

As diagrammed in Fig. 5, when this is used, the peel-away sheets of the high-frequency current suppression body 33 are peeled away and electronic components 49 and 51 are joined together. Thus, by deploying a high-frequency current suppression main body 47 between electronic components that each generate high-frequency noise, mutual interference and the like between electronic components can be prevented by suppressing spurious electromagnetic radiation, and high-frequency noise from the outside can also be suppressed.

In the second embodiment described in the foregoing, furthermore, $\text{Fe}_\alpha\text{-Al}_\beta\text{-O}_\gamma$ was used for the granular magnetic thin film 19, but, in the present invention, any magnetic body expressed by the general formula M-X-Y may be used, and the present invention is not limited to or by the second embodiment. Also, either one or both of the substrates 35 and 37 may be omitted if it is easy to handle.

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Referring to Fig. 6, a high-frequency current suppression body 53 according to a third embodiment of the present invention has a peel-away substrate 55 made of a carrier tape or the like, a granular magnetic film 57 deployed on that peel-away substrate 55, and a pressure-sensitive adhesive layer 59 deployed on the granular magnetic film 57. A peel-away sheet 61 is provided to prevent tackiness. For the pressure-sensitive adhesive layer 59, substances like those exemplified in the first embodiment can be used.

As diagrammed in Fig. 7A, when using the high-frequency current suppression body 53, the peel-away sheet 61 has been removed from the surface of the high-frequency current suppression body 53. Thereafter, the surface of the high-frequency current suppression body 53 is positioned so as to face the desired surface of a substrate 67. As diagrammed in Fig. 7B, pressure is applied with a punch 65 from the surface on the back side from the facing surface. Thereupon, as diagrammed in Fig. 7C, the adhesive layer 59 and the granular magnetic thin film 57 formed superimposed thereon separate together from the peel-away substrate 55, according to the shape of the pressing punch 65, and adhere to the substrate 67 as a high-frequency current suppression body film 69. Thus a high-frequency current suppression body of the desired shape can be formed at a desired site.

In the third embodiment of the present invention, moreover, the peel-away substrate 55 was used, but it is also permissible to provide the punch 65 with a heating mechanism, effect heating and fusion when applying pressure, solidifying the resulting fused resin, and adhesively applying the granular magnetic thin film, without providing the adhesive layer 59 and peel-away sheet 61.

This may be something having rubber or synthetic resin exhibiting tackiness between the peel-away substrate 55 and the granular magnetic thin

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saturation magnetization of a metal magnetic body consisting solely of the M component was 72.2%.

Table 1

Vacuum degree before deposition	$< 1 \times 10^{-6}$ Torr ($= 1.33 \times 10^{-4}$ Pa)
Atmosphere upon deposition	Ar
Power Supply	RF
Target	Fe (Diameter ϕ : 100mm) + Al_2O_3 chip (120 pieces) (Chip size: 5mm x 5mm x 2mm t)

In order to verify the magnetic loss characteristics of the sample, the μ -f characteristic was investigated. Measuring the μ -f characteristic is done by inserting the sample into a detection coil fashioned in a ribbon shape, and measuring the impedance while applying a bias magnetic field. Thus the frequency characteristics of the magnetic loss factor μ'' are obtained.

(Comparative Sample 1)

Comparative sample 1 was obtained by the same method and under the same conditions as sample 1 except in that the number of Al_2O_3 chips was made 90.

When the comparative sample 1 so obtained was subjected to fluoroscopic x-ray analysis, the composition of the film was found to be $\text{Fe}_{86}\text{Al}_6\text{O}_8$. The film thickness was 1.2 μm , the DC resistivity in comparative sample 1 was 74 $\mu\Omega\cdot\text{cm}$, the anisotropic magnetic field was 22 Oe (1738 A/m), and M_s was 18800 Gauss (1.88 T). The ratio between the saturation magnetization of comparative sample 1 and the saturation magnetization of a metal magnetic body consisting solely of the M component, that is, the value of $\{M_s(M-X-Y)/M_s(M)\} \times 100$, was 85.7%.

Referring to Fig. 10, in the μ'' -f characteristic, comparative sample 1 exhibits a large μ'' , reflecting the fact that the saturation magnetization M_s is large. However, because the resistance value of this sample is low, eddy current losses are generated as the frequency rises. Thus it is evident that a deterioration in the permeability (magnetic loss characteristic) has developed from the low-frequency region, and that the permeability characteristics have become poor at high frequencies.

Next will be described tests done to verify noise suppression effectiveness using the sample(s) obtained with the embodiments of the present invention.

Using the measurement system diagrammed in Fig. 11 to verify noise suppression effectiveness, and using a high-frequency current suppression body comprising the granular magnetic thin film of sample 1 having the permeability characteristic diagrammed in Figs. 4 and 5, formed in a square 20 mm on a side, with a film thickness of 2.0 μm , that was placed directly above a microstrip line having a line length of 75 mm and a characteristic impedance of 50 Ω , and the transmission characteristics between 2 Ports were determined using a network analyzer (HP 8753D).

In Table 2, the permeability characteristics for the high-frequency current suppression body sheet of the granular magnetic thin film sample 1 are given together with the characteristics for a composite magnetic body sheet of the same area consisting of flat Sendust powder and a polymer used as a

Table 2

Permeability Characteristics

	Granular Magnetic Thin Film	Composite Magnetic Sheet
$\mu''/700\text{MHz}$	about 1800	about 3.0
bwr	148	196

comparative sample. The μ'' of the granular magnetic thin film sample 1 exhibits a dispersion in the sub-microwave band, with a size $\mu''_{\text{max}} =$ approximately 1800 in the vicinity of 700 MHz. This is some 600 times larger than the μ'' of the comparative sample that exhibits μ'' dispersion in the same band. Furthermore, the relative bandwidth is small compared to that of the comparative sample, from which it is seen that this is a narrow band. When high-frequency currents are suppressed by deploying a magnetic loss material immediately next to a noise transmission path and imparting an equivalent resistance component to the transmission path, it is believed that the level of suppression effect will be roughly proportional to the product of the size of μ'' and the thickness of the magnetic body ($\mu'' \cdot \delta$), wherefore, when comparing suppression effects, a composite magnetic body sheet wherein $\delta = 1.0$ mm at $\mu'' \Rightarrow 3$ such that the value of $\mu'' \cdot \delta$ will be on the same order was used as the comparative example.

More specifically, as diagrammed in Fig. 11, the high-frequency current suppression body sheet was deployed directly over the conductor of a microstrip line 95 as indicated by the broken line 97, and the changes in the transmission characteristic S_{21} were determined. In Fig. 11, the symbol 99 designates a coaxial line.

In Figs. 12A and 12B, the S_{21} characteristics are plotted when deploying, respectively, the high-frequency current suppression body sheet of

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In the embodiments of the present invention, moreover, this is an as-deposition film, but the performance and characteristics can be altered after film fabrication by performing a heat treatment in a vacuum magnetic field.

Based on the foregoing, it is evident that the samples of the present invention that exhibit μ'' dispersion in the sub-microwave band exhibit a high-frequency current suppression effect equivalent to that of a composite magnetic body sheet having a thickness that is approximately 500 times greater, and that such are promising as materials used to minimize EMI, between electronic components comprising semiconductor integrated devices and the like that operate with a high-speed clock running near 1 GHz and electronic components mutually susceptible to interference, and in electronic components and circuit devices and the like that use high frequencies.

The granular magnetic films described in the foregoing relate only to $\text{Fe}_x\text{Al}_y\text{O}_z$, but it is evident that the granular magnetic thin film of the present invention can elicit the same effects even if, instead thereof, the components of the magnetic body with the general formula M-X-Y are such that M is Ni, Fe, or Co, the X component is C, B, Si, Al, Mg, Ti, Zn, Hf, Sr, Nb, Ta, or a rare earth, or, alternatively, a mixture of those, and the Y component is F, N, or O, or, alternatively, a mixture of those.

The film forming method used in the embodiments described in the foregoing was sputtering, but other methods such as vapor deposition or the like can also be employed. In addition, such manufacturing methods as ion

In the embodiments of the present invention, furthermore, description is given for high-frequency current suppression bodies comprising a synthetic resin substrate or an adhesive layer or pressure-sensitive adhesive layer comprising a synthetic resin, but it is permissible to form the granular magnetic film directly on the site of use, and form a protective film or the like on top of that, and the present invention is not limited to or by the method of adhesion or affixing.

Based on the present invention, as described in the foregoing, it is possible to provide a high-frequency current suppression body having a magnetic thin film exhibiting outstanding high-frequency magnetic loss characteristics extremely effective in eliminating interference caused by electromagnetic noise or spurious electromagnetic radiation from circuit boards using electronic components and/or high frequencies.